(54) AIRCRAFT AIR-CONDITIONING SYSTEM

(71) We, THE GARRETT COR-PORATION, a Corporation organised under the Laws of the State of California, United States of America, of 9851—9951 Sepulveda Boulevard, Los Angeles, California 90009, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement: —

In the conventional aircraft environmental control system in which an auxiliary power unit such as a gas turbine supplies bleed air to the air conditioning system, the gas turbine runs at its maximum power at all times during operation regardless of the demands of the air conditioning system. Since the air conditioning system only requires maximum bleed air from the gas turbine during intermittent operating conditions, uniform maximum power operation of the gas turbine is highly inefficient. Separate independent consideration and operation of the air conditioning system and auxiliary power unit does not provide for optimum overall performance.

The invention relates to an automatic control system between an aircraft Environmental Control System (ECS) and an aircraft Auxiliary Power Unit (APU).

According to the present invention, an aircraft air-conditioning system includes: a turbine engine having high-pressure and low-pressure spools and arranged to produce shaft power and bleed air; air-conditioning means arranged to receive and condition bleed air from the engine and to supply the conditioned bleed air to one or more temperature-controlled zones in the aircraft; and an automatic control means which is arranged to receive temperature signals from the temperature-controlled zone or zones, and to supply to the air-conditioning means a temperature demand signal dependent on the received signals to cause adjustment of the air-conditioning means to vary the temperature of the conditioned bleed air, and to

supply to the engine a signal to cause an increase in the speed of the low-pressure spool to enable the air-conditioning means to satisfy the demand signal whenever it cannot do so without such an increase.

Since the automatic control means is responsible for controlling the turbine engine and the air-conditioning means in response to signals from the temperature-controlled zone or zones, it is an example of the class of control means sometimes known as 'interface controls', which receive signals from one or more sources, and generate output signals in a suitable form for controlling the operation of one or more items of equipment. Where the term 'interface control' or 'interface control system' is used in the following description to describe a particular element, this simply means that that element is a control means of this class.

The invention may be put into practice in various ways but certain specific embodiments will be described by way of example with reference to the accompanying drawings in which: —

Figure 1 is a schematic representation of an aircraft Environmental Control System (ECS) and Auxiliary Power Unit (APU) in an airframe;

Figure 2 is a schematic functional diagram of the basic automatic interface control system of the present invention;

Figure 3 is a schematic drawing of an Auxiliary Power Unit (APU) engine useful with the interface control system of Figure 2;

Figure 4 is a schematic block diagram of the control functions for the APU of Figure 3;

Figure 5 is a graph of APU pressure versus APU bleed airflow for the interface control system of Figure 2;

Figure 6 is a schematic block diagram of the interface control system of Figure 2;

Figure 7 is a graph of the proportional plus integrating control scheme characteristics of the zone temperature control of Figure 6;

Figure 8 is a schematic functional diagram of the entire automatic interface control system;

Figure 9 is a schematic circuit diagram of the zone temperature control 39' of Figure 8;

Figure 10 is a schematic circuit diagram of the interface control 52' of Figure 8.

In Figure 1 an example of an Environmental Control System (ECS) for a tri-jet wide-bodied aircraft is schematically illustrated within an airframe. Bleed air from each of the three engines and the Auxiliary Power Unit (APU) is provided to three Air Conditioning Packs and thence to each of five temperature control zones through cabin hot air distribution ducts and conditioned air distribution ducts. The five temperature control zones include Cockpit Zone I, Underfloor Galley Zone II, Forward Cabin Zone III, Mid Cabin Zone IV, and Aft Cabin Zone V.

The Air Conditioning Packs may be any of the conventional refrigeration units used in aircraft ECS. For example, each air conditioning pack may be a three wheel air cycle unit including a single heat exchanger, water separator, water separator temperature control, turbine bypass valve, and ram air inlet and exit controls. Such a unit includes a bootstrap compressor and a cooling air fan mounted on a common shaft which is driven by a refrigeration turbine. Air from a flow control unit is compressed in the bootstrap compressor and discharged into the heat exchanger where the air temperature is reduced to near ambient by the flow of cooling ram air drawn through the heat exchanger by the fan. The cooled compressed air is expanded through the turbine and becomes refrigerated due to the energy extracted from the air to drive the refrigeration unit shaft. The refrigerated air enters the water separator where most of the free moisture content in the air is removed. The free moisture is prevented from freezing by a dew point control valve which is integral with the refrigeration unit. As soon as ice begins to form on a screen in the turbine discharge duct, the increase in pressure drop across the screen opens a valve to admit direct bleed air into an anti-ice muff around the turbine discharge duct. This raises the mixed air temperature and dispels the ice.

The temperature of the conditioned air supply to the cabin zones is controlled by a turbine bypass valve, which unloads the refrigeration unit, and a ram air inlet door and a ram air exit door, which reduce the cooling airflow through the heat exchanger. The ram air inlet and exit doors and the turbine bypass valve may be programmed together mechanically and controlled by an electronic refrigeration pack controller which maintains a specific conditioned air temperature determined by signals received from cabin zone temperature controllers. The cooled air is distributed to each of the five temperature control zones through the conditioned air cabin distribution ducts shown as stippled in Figure 1.

The basic automatic interface control system for use between an aircraft Environmental Control System (ECS) and an aircraft Auxiliary Power Unit (APU) is illustrated schematically in Figure 2. The APU and controls 10 receive fuel and develop a shaft power output in addition to the high bleed air pressure and temperature for the air conditioning packs and controls 11 which supply air at the proper temperature for the aircraft cabin zones and controls 12 of the ECS. The interface control 14 receives an inlet temperature demand signal and a trim heating demand signal from each of the cabin zones and controls 12 and supplies a speed demand to the APU and controls 10 and a pack outlet air temperature demand to the air conditioning packs and controls 11. In this manner the cabin zone temperature sensing intelligence controls the APU speed by means of the interface control 14 to ensure that sufficient air, at suitable temperature and pressure, can be supplied to the air conditioning packs.

In order to maintain a zone at a selected temperature, for example 75°F, under varying conditions, the air flow supplied to the zone has to be varied in temperature and/or in flow rate. These variations are achieved as far as possible by adjusting the air conditioning packs while maintaining the APU at a minimum speed setting. If greater variations are required, the cabin zone temperature control intelligence automatically adjusts the APU speed setting upward through the interface control 14.

As shown in Figure 3, a suitable APU 29 may comprise a low pressure compressor 15, high pressure compressor 16, high pressure turbine 17 and low pressure turbine 18. The high pressure compressor 16 and high pressure turbine 17 are on a common high pressure spool 19 which is used to drive AC generator 20 and hydraulic pump 21. The speed of the high pressure spool is regulated to a constant value N, by a fuel metering control which provides fuel through the fuel nozzles 22 for the combustor 23 where exhaust gases drive the turbines 17 and 18.

The low pressure compressor 15 and low pressure turbine 18 are on a common low pressure spool 24. Bleed air is extracted from the low pressure spool 24 at a point between the low pressure compressor 15 and high pressure compressor 16 and is controlled by a load valve 25 and surge valve 26. The first stage of the low pressure turbine 18 is provided with variable nozzles 27 so that

the speed N_1 of the low pressure spool 24 is variable and can be set to match the demands of either the air conditioning or engine starting systems.

Suitable APU controls for the APU 29 of Figure 3 are illustrated in Figure 4. An electronic N_1 speed control 30 which receives the speed demand from the interface control 14 is arranged to compare the N_1 demand signals from N_1 reference limits 31 while ECS is operating ON and N_1 reference limits 32 while ECS is operating OFF with the actual N_1 speed and uses the error signal to reposition the variable turbine inlet guide vanes of variable nozzles 27 by means of nozzle actuator 33. The APU engine 29 reacts to this change in geometry by a change in the N_1 speed. The N_2 speed control 34 for the high pressure spool 19 consists of a governor (not shown) that modulates fuel through the fuel nozzles 22. A more detailed description of the APU of Figure 3 and the APU controls of Figure 4 can be found in our Patent No. 1320530.

The APU pressure versus airflow diagram of Figure 5 illustrates the actual interface between the air conditioning packs of the ECS and APU design characteristics. Diagram ABCD represents pressure versus airflow for two air conditioning packs operating while diagram EFGH represents pressure versus airflow for three air conditioning packs operating. Line J represents a minimum APU condition of N_1 being 56% of maximum while line K represents a minimum ECS condition with N_1 being 78%. Maximum ECS condition with N_1 equalling 93% is represented by line L, while maximum APU N_1 speed of 100% is represented by line M. Point I on speed line K denotes the typical mode of operation. The APU speed N_1 is 78% and bleed airflow from the APU is approximately 300 lbs. per minute. Along this line K the temperature of the air delivered by the air conditioning pack is modulated as far as is possible while maintaining the N_1 speed of the APU at 78%. The

modulation of the air delivery temperature will also cause a variation in the pressure and flow rate of the air bled from the APU, as can be seen from Figure 5. The minimum temperature condition imposes the highest pressure on the APU while the maximum temperature condition imposes the least pressure on the APU and the flow therefore increases with increasing zone inlet temperature demand.

When simple modulation of the air conditioning packs at an APU N_1 speed of 78% can no longer maintain all the temperature control zones at the selected temperature, the APU speed is increased from line K towards line L. If the air conditioning packs are operating at their maximum temperature settings, the operating point of the packs will move towards point "G". Beyond this point the air conditioning pack flow control unit restricts the air flow to approximately 450 lbs. per minute, and there is a corresponding increase in the pressure and temperature of the bleed air. Point III on line L represents the maximum heating supply by the APU as the need arises for higher supply air temperature. As an example, on a $-45°F$ day, N_1 APU speed of 78%, the supply air temperature will be of the order of 50°F, well below that which is required to heat up the cabin. Under such conditions it is necessary to increase the APU speed in order to increase the supply air pressure and consequently air temperature.

Point II on line L denotes the maximum cooling mode of operation, which is required on a very hot day on the order of 110°F. In this case the APU is required to supply 350 lbs. of bleed airflow per minute at maximum pressure; for this, the N_1 APU speed is increased to 93%.

The table below shows the fuel consumption at each of operating Points I, II and III and illustrates the potential savings in fuel consumption achieved by modulating N_1 speed rather than operating at a fixed N_1 speed of 93%.

	Temp. Ambient °F	Bleed Airflow lb/min.	Load hp	Mode	Fuel Consumption lb/hr	N_1 Speed
I	65	300	100	Normal	290	78%
II	65	370	100	Maximum Cooling	415	93%
III	65	450	100	Maximum Heating	440	93%

Fig. 6 schematically illustrates the automatic interface control system between the ECS and the APU. The system basically comprises a zone temperature control 39, interface control 52, APU control 60 and air conditioning pack temperature control 61. While shown in its simplest form for purposes of illustration, it should be recognized that in any system there may be a plurality of zone temperature controls 39, one for each cabin zone with each having its own associated elements. Likewise, there may be a plurality of air conditioning pack temperature controls 61, one for each air condition-

ing pack with each of these having its own temperature sensor. The air conditioning pack controls are interfaced with the zone temperature controls via a single interface control unit 52.

The interface control 52 receives inlet temperature demand signals and trim heating demand signals from all respective zone temperature controls and generates air-conditioning pack outlet air temperature demand signals in a normal mode of operation corresponding to an N_1 APU speed of 78%. The lowest of the inlet temperature demand signals is utilized to set the air conditioning pack outlet air temperature in a preselected range, for example, from 20°F to 165°F. The air-conditioning packs, therefore, operate in parallel, supplying identical supply air temperature, satisfying at least one of the plurality of temperature control zones. In the temperature in one or more of the zones remains above the selected temperature, despite adjustment of the air-conditioning packs to supply air at the lowest temperature possible at an APU N_1 speed of 78% of the maximum N_1 speed, the corresponding zone inlet temperature demand signal or signals will represent a demand for even cooler air; these signals can therefore alternatively be termed 'More Cool' signals. Under these conditions, the APU N_1 speed is increased above 78% of its maximum value, so that more air at a higher pressure is supplied to the air-conditioning packs, allowing them to produce more cool conditioned air.

If there are slight variations in heat load among the zones, so that one zone requires a few degrees higher air temperature than another zone, the trim heating demand signals cause small heat supply trim valves to be automatically adjusted to increase the supply air temperature above that supplied by the air-conditioning packs. Each zone, therefore, has an independent control means of adding heat through the modulation of the small trim heat supply valves. When these trim heat supply valves are unable to satisfy the zone temperature controls it is necessary to increase the N_1 APU speed above 78% and increase the amount of hot air available to the trim valves. The trim heating demand signals can therefore alternatively be termed 'More Heat' signals.

In its simplest form, the zone temperature control 39 for zone I utilizes a zone temperature selector 40 and zone temperature sensor 41 fed to a summer 42 to produce an error signal. This error signal is fed to both an integrating channel 43 and a proportional channel 44 to produce the zone inlet temperature demand signal which is supplied to the interface control 52. This same signal is fed to limiter 45 to form a limited zone inlet temperature demand signal in a preselected range, for example, between 20°F and 165°F. This limited signal is then fed to summer 46 which compares it to a signal from the zone inlet temperature sensor 47 to provide the trim heating demand signal to the trim heat control 48 which controls the trim heat control valve 49. The trim heating demand signal represents the amount by which the actual zone inlet temperature is less than the temperature represented by the limited zone inlet temperature demand.

The zone I trim heating demand signal is also fed to a trim heating discriminator 56 in the interface control 52 which also receives trim heating demand signals from each of the other zones to produce a signal corresponding to the greatest of the trim heating demand signals.

Four other zone inputs are shown for purposes of illustration. A trim heating mode speed filter 53, which receives the signal from the discriminator 56, produces an APU speed demand signal which is passed through a stabilisation network 50 and then to a maximum APU speed discriminator 58 which provides a speed command to the N_1 speed control 30 of the APU control 60.

The zone inlet temperature demand signals from all temperature zone controls 39 are likewise fed to the interface control 52. The zone inlet temperature demand signal from zone I, together with the zone inlet temperature demand signals from zones II, III, IV and V, is fed to a minimum inlet temperature demand discriminator 57 to produce a command signal for the air conditioning pack control 51 of the air conditioning pack temperature control 61 to adjust it to the lowest zone inlet temperature required. The air conditioning pack control 51 receives this command signal through limiter 76. The pack outlet temperature is sensed by the outlet temperature sensor 79, and the control 51 compares the command signal from the limiter 76 with the signal from the sensor 79. If there is any difference between the two signals, the control 51 adjusts the turbine bypass and the ram air doors 62 to bring the outlet temperature signal closer to the command signal.

As an example, if the lowest of the plurality of zone inlet temperature demands is 45°F, the pack temperature control 51 of the air conditioning pack temperature control 61 will adjust the turbine bypass and ram air doors 62 to supply a 45°F air temperature. In the event that another zone temperature control is demanding air at a slightly higher temperature, say 50°F, the necessary compensation will be made by independently adjusting the trim heating valve 49 and thereby increasing the zone inlet temperature by 5°F.

The command signal from the discriminator 57 is also provided to the maximum APU speed discriminator 58 through a speed filter

59. The discriminator 58 thus receives one signal from the stabilization network 50 and another from the filter 59, and functions to send which ever of these signals represents the higher N_1 speed as a speed demand signal to N_1 speed control 30. The N_1 speed control 30 controls the N_1 speed of the APU 29.

The characteristics of the proportional plus integrating control scheme of the zone temperature control 39 are shown graphically in Figure 7. The zone temperature control 39 incorporates a proportional channel 44 and an integrating channel 43. Typically, a zone temperature control would only have a proportional channel with a proportionally amplified error signal. Generally, an error can be amplifier by any desired factor but the higher the amplification, the less stable the temperature control system. A proportional channel with a gain of 11, meaning that a 1°F change would impose only an 11°F change at the zone inlet, is not adequate for accurate zone temperature control.

On the other hand, the characteristic of the integrating channel is that for a given error at its input, it integrates this error as a function of time, thus, for an error of 1°F at its input, an integrator with a gain of 1/17 per second will have an output of 1°F after 17 seconds. Therefore to compensate for the low accuracy of a low gain proportional channel, the integrator can be utilized to eliminate any proportional error in time. This compensation provides for a stable and accurate overall temperature control system as shown schematically in the graph. The integrator output is limited to ±60 degrees F; the combined output of the channels is limited to the range between 5°F and 170°F. In this manner, the undesirable temperature overshoot can be prevented after restarting the system operation while integrator output is in its extreme setting.

The electronic interface control system of Figure 6 is illustrated in more detail in Figure 8. Summer 42' produces an error signal from zone I temperature selector 40' and zone I temperature sensor 41', and feeds this error signal to the integrating channel 43' and proportional channel 44'. The integrating channel 43' comprises a null reset integrator 67 and an integrator reset authority limiter 68. The proportional channel 44' comprises a proportional channel amplifier 65 and summer 66 to bias the proportional channel signal to a preselected temperature, in this example 70°F. The proportional and integrating channels share summer 69 which produces the zone inlet temperature demand signal. This signal is fed to the minimum inlet temperature demand discriminator 57' of the interface control 52' and also to the zone inlet temperature demand limiter 45'. Summer 46' receives the signal from the

limiter 45' and the signal from the zone inlet temperature sensor 47' to produce a trim heating demand signal which is fed to the trim heating discriminator 56' of the interface control 52' and to the control power amplifier 48' which controls the trim heat control valve 49'.

The trim heating discriminator 56' receives the trim heating demand signal from each of the zones and selects the maximum trim heating demand signal to pass to the trim heating mode speed filter 53' which produces a signal for the stabilization network 50'.

Likewise, the discriminator 57' receives the inlet temperature demand signals from each of the zones and selects the minimum inlet temperature demand signal which is fed to the APU speed command filter 59' and the limiter 76' of the air conditioning pack I temperature control 61' and any other air conditioning pack temperature controls (Packs II and III). The maximum APU speed discriminator 58' receives the signal from the stabilization network 50' and the APU speed command filter 59' to produce a speed signal for the N_1 speed control 30' which controls the N_1 speed of APU engine 29'.

The limiter 76' produces a temperature command signal for the temperature control 51' of the air conditioning pack temperature control 61'. Control 51' also receives a feedback signal from the air conditioning pack outlet air temperature sensor 79' for comparison with the temperature command signal to determine whether any change is necessary in the setting of the turbine bypass and the ram air doors. Air conditioning pack I 78 receives bleed air from the APU engine 29' plus ambient air to produce cool air. Bleed air from the APU engine 29' is passed through the air conditioning pack I 78 airflow control to limit the total bleed airflow used. A portion of this flow may be fed through the trim heat control valve 49'; the remainder is conditioned in the air conditioning pack I 78.

As shown in Figure 9, the summer 42' may comprise a circuit of resistors 84, 85, 86 and 87 plus summing amplifier 88. The integrating channel 43' and proportional channel 44' may together comprise circuit 80 including resistors 89, 90, 91, 95, 97, 98, 99, 101 and 102 plus capacitor 92, diodes 93 and 94 and operational amplifiers 96 and 100.

The circuit for the temperature command limiter 45' comprises diode 105 and zener diodes 103 and 104. The summer 46', comprising resistors 107 and 112 plus summing amplifier 108 is connected to the circuit 80 through resistor 106. Operational amplifier 111 receives a signal from the zone inlet temperature sensor 47' through resistor 109 to provide a signal to the summer 46' which

produces a signal for the control power amplifier 48' and the trim heating discriminator 56' through a power amplifier 114. The minimum inlet temperature demand discriminator 57' receives a signal through power amplifier 113.

As shown in Figure 10, discriminator 57' comprises resistors 120, 121, 122, 123 and 124 connected in parallel plus diodes 125, 126, 127, 128 and 129. Each resistor receives an inlet temperature demand signal from one of the five zones. The APU speed command filter 59' comprises resistors 130, 131, 133, 134, operational amplifier 132 plus diodes 135 and 136.

The trim heating discriminator 56' likewise comprises a parallel circuit of resistors 150, 151, 152, 153 and 154 plus diodes 155, 156, 157, 158 and 159 and receives trim heating demand signals from the five zones. The stabilization network 50' comprises resistor 145 and capacitor 146 and is connected in parallel to the APU speed command filter 53' which comprises resistors 140, 141, 142 and 143, operational amplifier 144, and diode 137. Diodes 135 and 137 also comprise the maximum APU speed discriminator 58'. Signals from the filters 59' and 53' are fed to operational amplifier 160 through resistor 165. Amplifier 160 is also connected to ground through resistor 166. A speed command signal to the APU N_1 speed control 30' is provided through power amplifier 161.

Generally the zone inlet temperature can be controlled in three separate ways. First, it can be adjusted by modulating the air conditioning packs outlet temperature by varying the setting of the turbine bypass and the ram air doors; second, it can be adjusted by the trim heat valve and its associated controls; and third, it can be adjusted by adjusting the APU N_1 speed in the range between 78% to 93% of its maximum value. To control the air conditioning packs, the lowest zone inlet temperature demand signal is fed simultaneously to all air conditioning pack controls and is compared with actual pack outlet temperatures. Any difference from this comparison will modulate the air conditioning pack bypass valves and ram air doors. The turbine bypass valve will adjust the amount of cooling achieved in the turbine while the ram air door adjusts the amount of cooling achieved through the heat-exchanger and the ram air circuit.

To control the trim heat valves, each zone inlet temperature demand feeds the corresponding zone inlet temperature control and this demand is compared with the actual zone inlet temperature. The resulting error is amplified and the trim heat valve moves automatically to a new desired position.

In the case where the temperature of the air supplied by the APU is considerably lower than the inlet temperature demand, the error between the demanded and actual inlet temperature may remain in excess of a nominal 3°F. If this occurs, the APU speed will then be increased by the trim heating demand signal (More Heat Signal. The setting of 3°F is maintained to insure that the APU speed augmentation is used only when absolutely necessary. If the error increases from 3°F to say 15°F, the APU speed will increase proportionally from 78% to 93%.

The APU speed is also increased when an increased cooling capacity is needed. As soon as the minimum cabin inlet temperature demand drops below 20°F, it is assumed that all available cooling capacity extracted through the air conditioning packs operated at 78% of APU speed is exhausted. Since the air conditioning packs should not supply air at temperatures lower than 25°F, depending upon the humidity of air, an increase in cooling capacity can only be achieved by augmenting the airflow. As the minimum temperature demand (More Cool Signal) drops from 20°F to 5°F, the APU speed is programmed to increase proportionately from 78% to 93%, at which speed the maximum airflow is supplied to the zone.

WHAT WE CLAIM IS:—

1. An aircraft air-conditioning system including: a turbine engine having high-pressure and low-pressure spools and arranged to produce shaft power and bleed air; air-conditioning means arranged to receive and condition bleed air from the engine and to supply the conditioned bleed air to one or more temperature-controlled zones in the aircraft; and an automatic control means which is arranged to receive temperature signals from the temperature-controlled zone or zones, and to supply to the air-conditioning means a temperature demand signal dependent on the received signals to cause adjustment of the air-conditioning means to vary the temperature of the conditioned bleed air, and to supply to the engine a signal to cause an increase in the speed of the low-pressure spool to enable the air-conditioning means to satisfy the demand signal whenever it cannot do so without such an increase.

2. A system as claimed in Claim 1 which includes respective temperature control means arranged to control the or each temperature controlled zone, the or each temperature control means being arranged to supply a respective trim heating demand signal and a respective main demand signal to the automatic control means, and also being arranged to supply the respective trim heating demand signal to control means which are arranged to control the flow of bleed air from the engine to the respective temperature-controlled zone.

3. A system as claimed in Claim 2 in

which the or each temperature control means is arranged to receive signals from a respective sensor arranged to sense the air temperature in the respective zone and from a respective desired temperature selector.

4. A system as claimed in Claim 3 in which the or each temperature control means includes: first summing means arranged to receive the signals from the sensor and from the selector and to supply an error signal to a controller, the controller being arranged to produce a proportional-plus-integral output signal constituting the main demand signal; a limiter arranged to receive the controller output signal; and second summing means arranged to receive an output signal from the limiter and a signal from a sensor arranged to sense the temperature of the conditioned air supplied to the associated zone, the output of the second summing means constituting the trim heating demand signal.

5. A system as claimed in Claim 4 in which the or each controller includes a null reset integrator arranged to integrate the error signal and to supply the integrated signal through an integrator reset authority limiter to a third summing means which is also arranged to receive the error signal and to provide a signal constituting the controller output signal.

6. A system as claimed in any one of Claims 2 to 5 which includes a plurality of temperature-controlled zones, and in which the automatic control means includes a trim heating discriminator arranged to receive the trim heating demand signals from all the temperature control means and to supply the greatest trim heating demand signal to a trim heating mode speed filter, and a main discriminator arranged to receive the main demand signals from all the temperature control means and to supply the main demand signal representing the lowest temperature to a main speed filter, the trim heating mode speed filter being arranged to supply a speed command signal through a stabilization network to a speed discriminator, and the main speed filter being arranged to supply a speed command signal to the speed discriminator, the speed discriminator being arranged to supply the greater speed command signal as an output signal for controlling the speed of the low-pressure spool of the engine.

7. A system as claimed in Claim 6 in which the trim heating and main discriminators each comprise a network of resistances and diodes, the trim heating mode and main speed filters each comprise an amplifier with a resistive feedback network, the stabilisation network comprises a series resistor-capacitor network connected in parallel with a portion of the feedback network of the trim heating mode speed filter, and the speed discriminator comprises a pair of diodes and a zener diode.
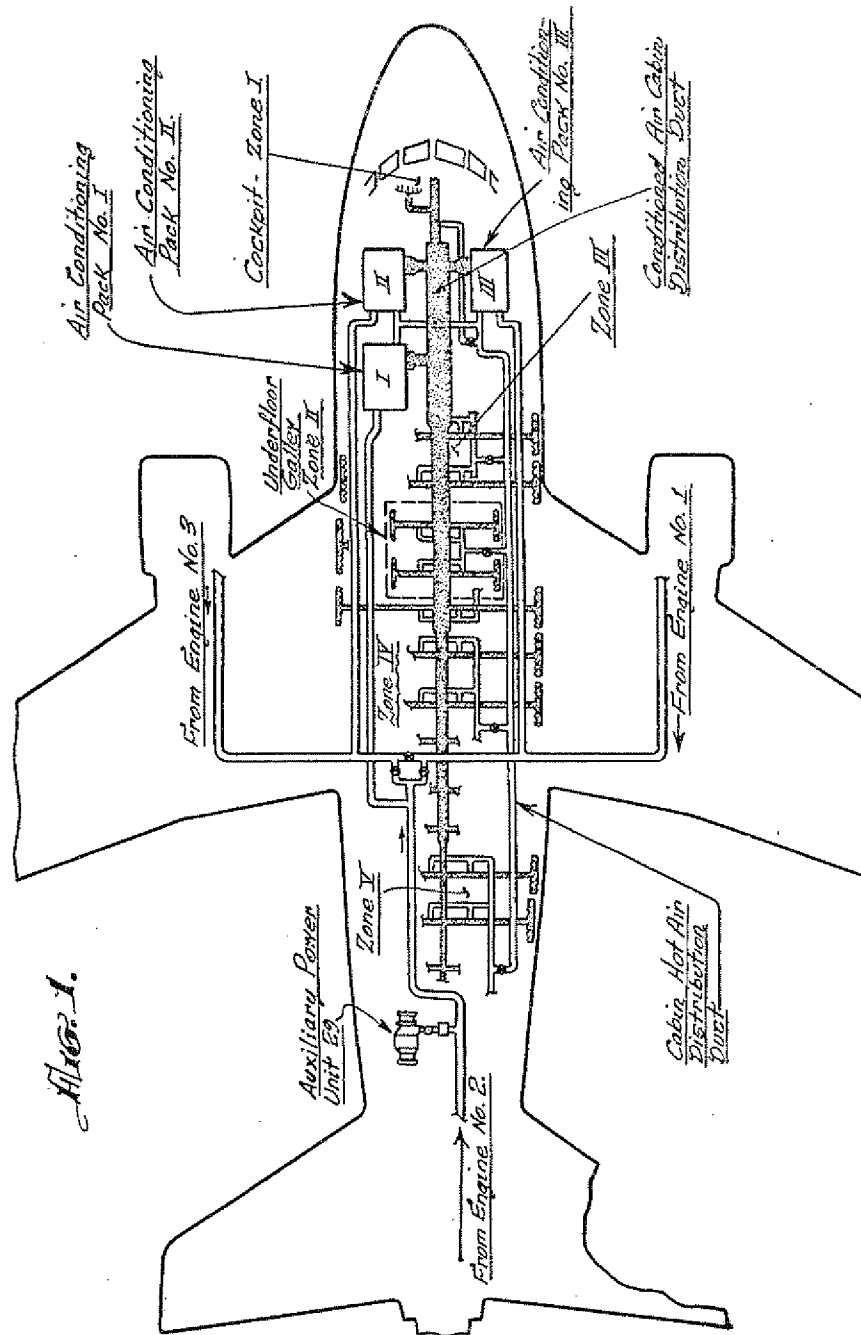
8. A system as claimed in any one of the preceding claims in which the low-pressure spool of the engine carries a low-pressure compressor rotor and a low-pressure turbine rotor at opposite ends, the high-pressure spool surrounds the low-pressure spool and carries a high-pressure compressor rotor at it end adjacent the low-pressure compressor rotor and a high-pressure turbine rotor at its other end, means are provided to extract bleed air from the flow from the low-pressure compressor to the high-pressure compressor, and variable nozzles are provided in the flow path from the high-pressure turbine to the low-pressure turbine to control the speed of the low-pressure spool.

9. A system as claimed in any one of preceding claims in which the engine has automatic governor means arranged to receive a low-pressure spool speed demand signal and to control the low-pressure spool speed to correspond to the said speed demand signal and the automatic control means serves to modify the said speed demand signal.
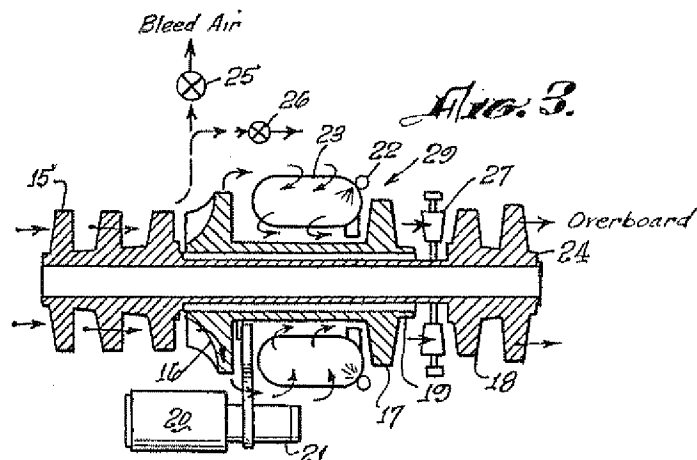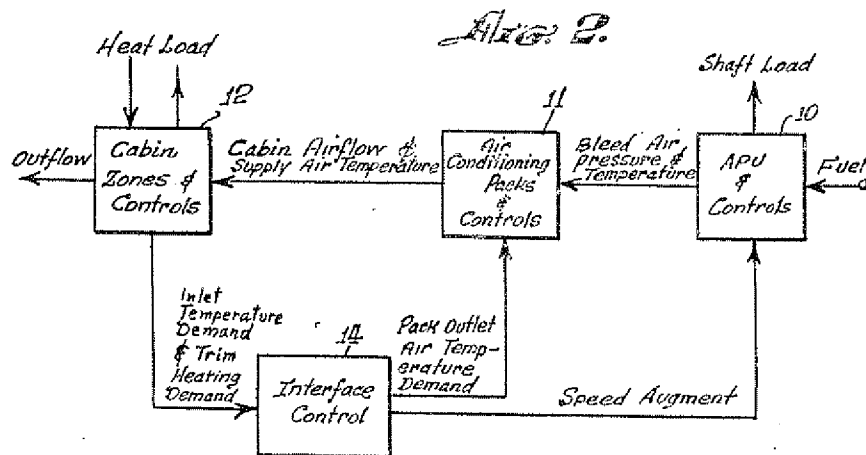
10. A system as claimed in any one of the preceding claims in which the engine normally operates at a speed substantially below its maximum value, and the automatic control means is arranged to increase the speed above the normal value when the conditioning means is unable to meet the demand for heating or cooling at the normal speed.
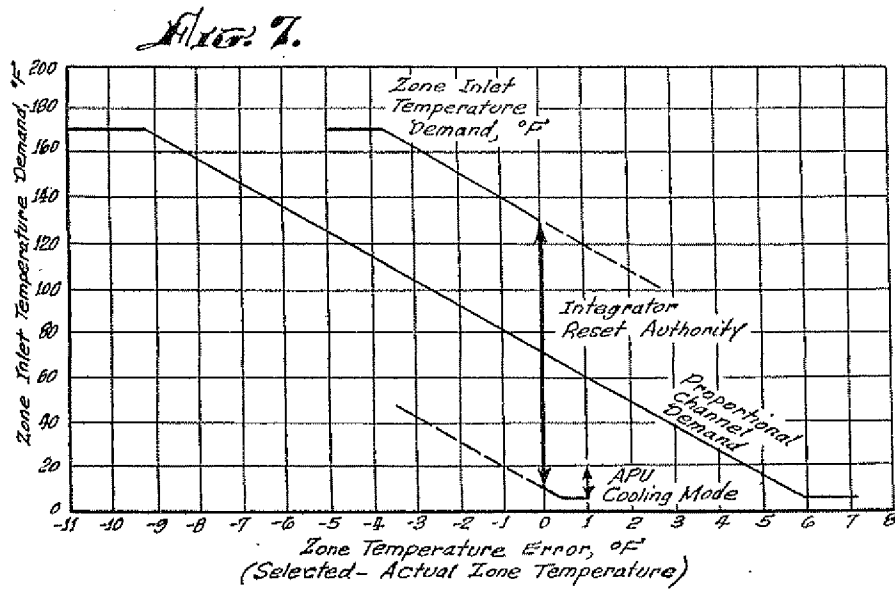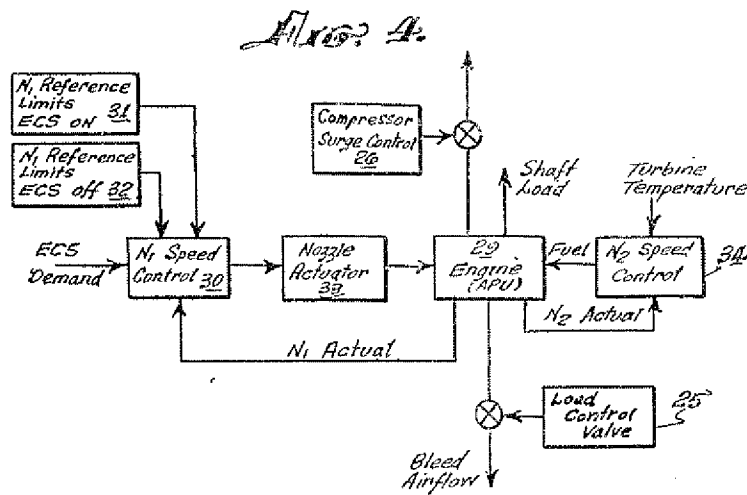
11. An aircraft environmental control system as specifically described herein with reference to the accompanying drawings.
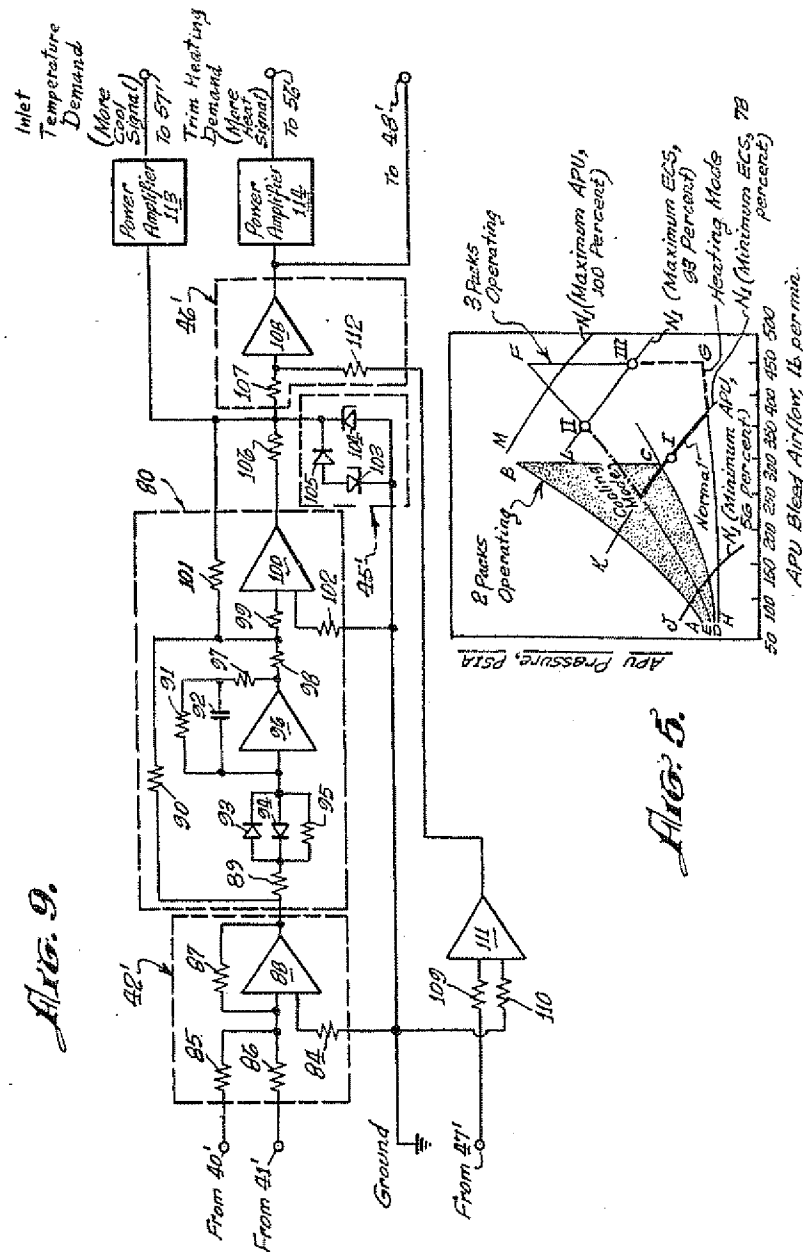
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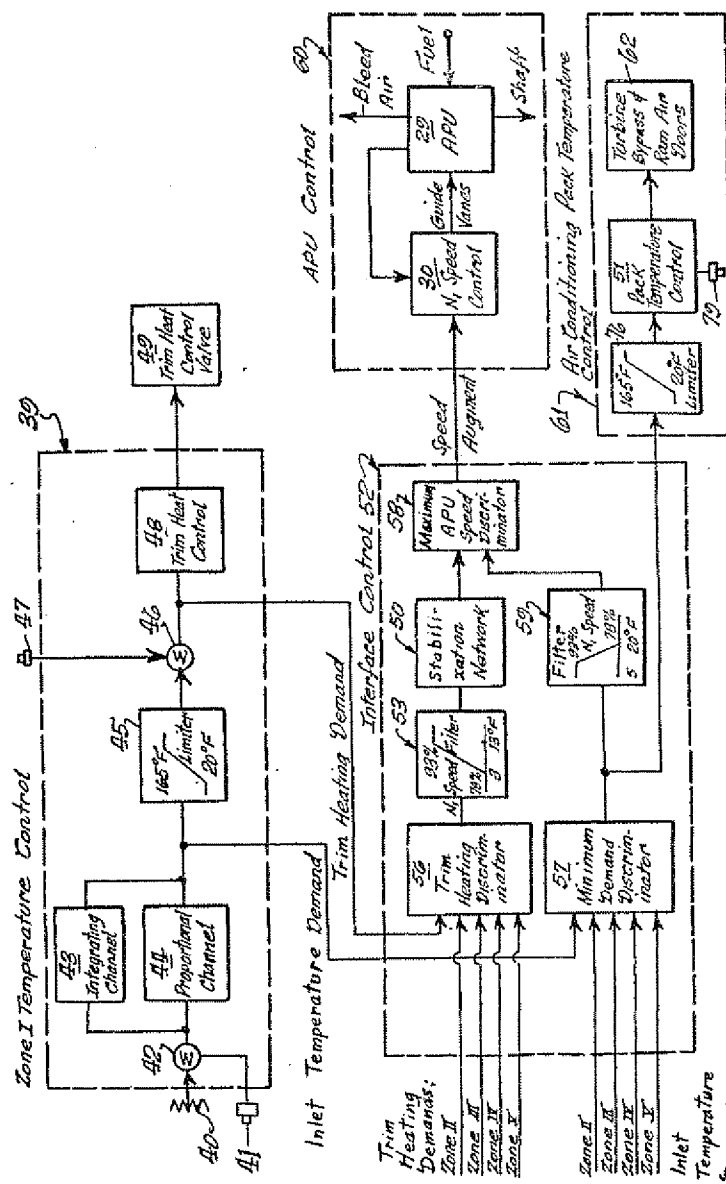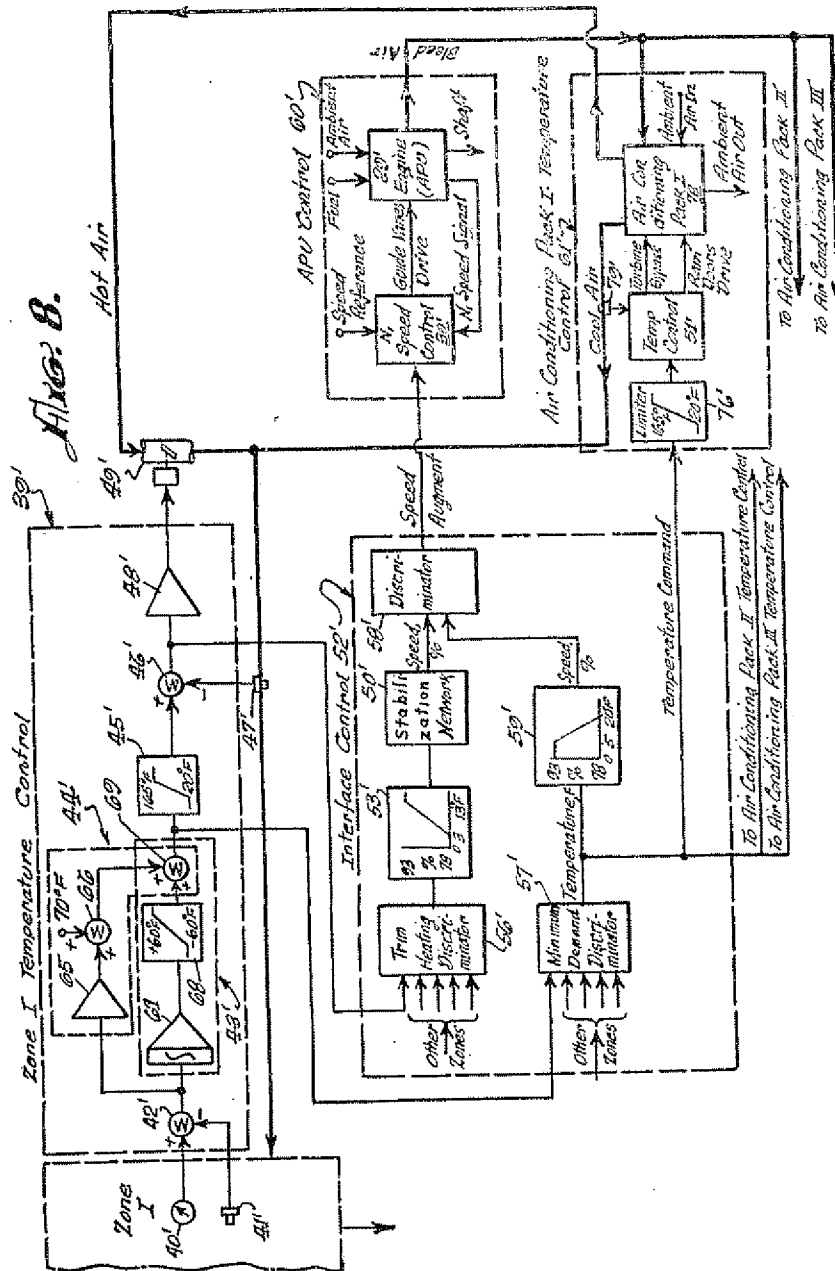Agents for the Applicants.

FIG. 1.

Fig. 2.

Heat Load

Outflow ← | Cabin Zones & Controls | 12 | Cabin Airflow & Supply Air Temperature | Air Conditioning Packs & Controls | 11 | Bleed Air Pressure & Temperature | APU & Controls | 10 | Fuel

Shaft Load

Inlet Temperature Demand & Trim Heating Demand

Pack Outlet Air Temperature Demand

| Interface Control | 14

Speed Augment

Fig. 3.

Bleed Air

⊗ — 25

26

23

22 29

27

15

Overboard

24

16

19   18

17

20

21

FIG. 4.

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┌──────────────┐
│ N₁ Reference │
│ Limits    31 │
│ ECS on       │
└──────────────┘
┌──────────────┐                    ┌──────────────┐
│ N₁ Reference │                    │ Compressor   │        ⊗
│ Limits    32 │                    │ Surge Control│
│ ECS off      │                    │      26      │
└──────────────┘                    └──────────────┘
                                                         Shaft      Turbine
                                                         Load       Temperature
  ECS      ┌──────────┐   ┌──────────┐   ┌──────────┐         ┌──────────┐
 Demand    │ N₁ Speed │   │ Nozzle   │   │    29    │  Fuel   │ N₂ Speed │   34
───────────│ Control30│──▶│ Actuator │──▶│ Engine   │◀────────│ Control  │───
           │          │   │    33    │   │  (APU)   │         │          │
           └──────────┘   └──────────┘   └──────────┘         └──────────┘
                ▲                                      N₂ Actual ▲
                │          N₁ Actual                    │
                └──────────────────────────────────────┘

                                      ⊗◀────┌──────────────┐  25
                                            │ Load         │
                                            │ Control      │
                                  Bleed     │ Valve        │
                                  Airflow   └──────────────┘
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FIG. 7.

FIG. 9.

FIG. 6.

FIG. 6.

FIG. 8.

FIG. 10.